Understanding a relay's operation can prevent trouble down the line

DOUG LIONETTI, AROMAT CORP

The venerable relay has undergone some changes in the past few years. Designers have supplemented conventional SSRs with optically coupled SSRs, challenging the familiar EMRs. You should understand the operation of these SSRs to get the best performance results.

The term "relay" generally designates a device that provides an electrical connection between two or more points in response to a control signal. The most common type, the electromechanical relay (EMR), has been around for over 100 years. During the past several decades, solid-state relays (SSRs), such as silicon-controlled rectifiers (SCRs), emerged. In the last few years, the optically coupled MOSFET, the PhotoMOS relay, has become available. The PhotoMOS relays have LED inputs and MOSFET outputs that provide input-to-output isolation that compares with the isolation obtainable from EMRs. **Table 1** compares the major functional characteristics of the relays.

PhotoMOS relays appear to beat SSRs and EMRs (**Table 1**). However, SSRs and EMRs continue to prevail in certain cases, such as heavy loads. PhotoMOS devices capable of handling loads in excess of 1A became available in 1993. Currently, PhotoMOS devices that have the highest capacity can switch as much as 4A at 60V dc. For lower currents, you should consider PhotoMOS relays for every relay application.

Over the years, relay manufacturers have developed a terminology and data-sheet format that you should understand before selecting a relay. However, relay terminology, particularly relay ratings, is not easily understood. **Fig 1** shows a specifications summary of a typical data sheet for Aromat's ultraslim polarized relay, the TN-relay. SSR and PhotoMOS specification sheets differ slightly from EMR specification sheets, and some of the confusion comes from the EMR specifications. The EMR specifications fall into two broad categories—contact and coil characteristics. Although the complete specification may take three to four pages, a summary is sufficient to make a preliminary decision as to whether a particular relay fits the application.

If you have read the "Definition of Relay Terminology" in Aromat's data book, you are familiar with the statement "arrangement is 2 form C." The confusion can come from

TABLE 1—RELAY-SPECIFICATION COMPARISON

Parameters	PhotoMOS	EMR	SSR
High reliability*	X		X
Infinite life*	X		X
Fast operation	X		X
100% contact stability*	X		X
Quiet—no audible noise	X		X
No EMI	X		X
Insensitive to magnetic fields*	X		X
Small size/high density*	X		X
Any-position mounting**	X		X
High I/O isolation* (1500V and up)	X	X	
Switches low analog/digital signals	X	X	
No zero crossover problem	X	X	
Surface mounting in the SO package	X		
Parallel operation	X		
Controlled rise and fall times	X***		
Switching currents about 4A		X	X

* Especially important in PhotoMOS versus reed-switch applications
** CRUCIAL versus mercury-wetted units
*** Developed in 1994

the initial-contact resistance, which is the maximum contact resistance of a new relay before you take it out of the box and place it into a circuit. The initial-contact resistance is commonly measured by passing a certain current through the contacts and noting the resultant voltage drop. For the case in **Fig 1**, the initial-contact resistance is 1A×0.06ω=0.06V dc.

Fig 2a better explains this concept. The initial (out-of-the-box) resistance is somewhat greater than after about 100,000 operations. This decrease in resistance occurs because the relays hit one another as they close, causing the contact surface to become smooth. The smoother surface lowers the initial resistance. This action is particularly prevalent in relays with gold-plated contacts.

As the contacts begin to wear, and if they are not properly protected, they show signs of arcing damage, and the contact resistance begins to increase gradually. You have to decide how much contact resistance the application can tolerate before you have to replace the relay. In SSRs and PhotoMOS relays, the contact resistance, or on-resistance, remains stable throughout the life of the relay.

The next important consideration is the relay's contact material. **Table 2** presents characteristics of some common contact materials. Even with the aids in **Table 2**, you may still be confused as to the meanings of terms such as cladding, plating, and flash plating. Cladding results in a gold layer of more than 5 microns thick. Plating implies a gold-layer plating of more than 2 microns and less than 5 microns. Flash plating means that the gold layer is less than 2 microns. Obviously, in the case of SSRs and PhotoMOS relays, there is no such concept as contact material.

The limitations of power-switching curves

The switching capabilities of a relay raise questions because switched power does not relate to the switched cur-

FIGURE 1

SPECIFICATIONS

Contact

Arrangement			2 Form C
Initial contact resistance, max. (By voltage drop 6V DC 1A)			60mΩ
Contact material			Gold-clad silver
Rating (resistive load)	Max. switching power		30W, 62.5VA
	Max. switching voltage		110V DC, 125V AC
	Max. switching current		1A
	Min. switching capability		10μA, 10mV DC
UL/CSA rating			1A 30V DC 0.5A 125V AC 0.3A 110V DC
Expected life (min. operations)	Mechanical (at 180cpm)		10^8
	Electrical (at 20cpm)	1A 30V DC resistive	2×10^5
		0.5A 125V AC resistive	10^5

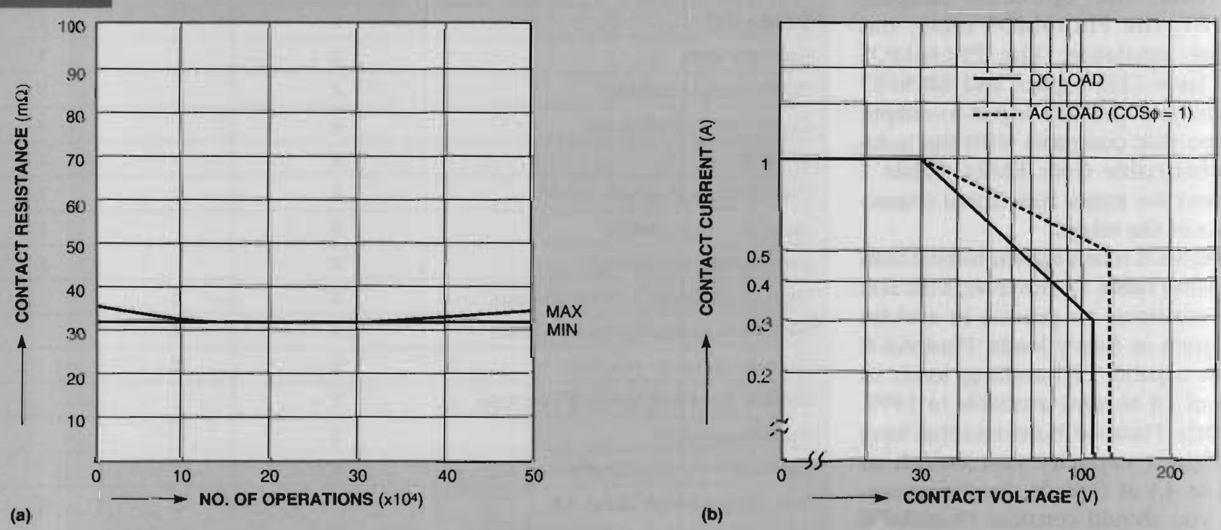
Characteristics

Max. operating speed (at rated load)		20cpm
Operate time* (at nominal voltage)		Max. 3msec. (Approx. 2msec.)
Release time* (at nominal voltage)		Max. 3msec. (Approx. 1msec.)
Set time* (latching) (at nominal voltage)		Max. 3msec. (Approx. 2msec.)
Reset time* (latching) (at nominal voltage)		Max. 3msec. (Approx. 2msec.)
Initial breakdown voltage	Between open contacts	750Vrms for 1 min.
	Between contact sets	1,000Vrms for 1 min.
	Between contact and coil	1,000Vrms for 1 min.
FCC surge voltage between open contacts		1,500V
Initial insulation resistance		Min. 1,000MΩ (at 500V DC)
Temperature rise (at nominal voltage)		Max. 50°C
Ambient temperature		−40°C to +70°C −40°F to +158°F
Shock resistance	Functional	Min. 490m/s² (50G)
	Destructive	Min. 980m/s² (100G)
Vibration resistance	Functional	176.4m/s² (18G), 10 to 55Hz at double amplitude of 3mm
	Destructive	294m/s² (30G), 10 to 55Hz at double amplitude of 5mm
Unit weight		Approx. 1.5g .053oz.

*Excluding contact bounce time

In this typical specification data sheet for an Aromat TN-relay, the specification falls into contact and characteristic categories.

FIGURE 2



The contact resistance of an EMR is slightly higher when taken out of the box and at long life, due to wear (a). The maximum switching-power rating for an EMR follows two curves, dc and ac, that don't conform to Ohm's law (b).

rents and voltages in accordance with Ohm's law. For example, a TN relay can switch 30W. You may wonder if you can switch 2A at 12V dc because it is less than 30W. Electromechanical devices have separate maximum ratings for power, current, and voltage that are not related to Ohm's law. You should consult the maximum switching-power curve as a function of current and voltage to determine the safe switching-power limits for a given relay. **Fig 2b** depicts such empirically derived curves for the TN relay, a dc curve, and an ac curve. The maximum current limitation for dc and ac curves means the relay can switch this current at any voltage ranging up to 30V, where the current meets the device's 30W power limit. The current then dips to stay within the power limit as the voltage increases up to as the voltage limit of 110V dc. For safe operation, you must stay under the curves.

Relay-life expectancy is specified as mechanical, such as a relay turned on and off without any electrical load on the contacts, or electrical, either ac or dc. The mechanical-life expectancy is easier to comprehend than the electrical-life expectancy because of the test conditions under which the electrical life is determined. Because you can't test a relay under every kind of loading, such as inductive, motor, capacitive, lamp, etc, you perform most electrical-life tests with a pure resistive load. A load that remains unchanged throughout the test is a wire-wound resistor. You must determine life expectations under any conditions other than resistive on a case-by-case basis. However, you can obtain certain data for some loads from the relay manufacturer.

The operate-time specification is also ambiguous. Aromat specifies it as the approximate value in msec. The reason for the ambiguity is bounce. It is well known that every EMR has some bounce before a solid continuous contact is made. Aromat specifies the operate time from the instant the device is energized to the instant the first contact is made, without including the bounce. In PhotoMOS relays, the operate time is well-defined because there is no bounce.

A relay with an operate-time specification of 30 msec is within many customer's needs. In most commercial, industrial, and consumer applications, the operate time is seldom an issue. However, if the operate time becomes an issue, and a relay must operate much faster, discussions with an application engineer become necessary. If you really need and can pay for an accurate operate time, you can ask the vendor to select for shipment only units that meet a minimum operate-time specification.

Ambiguous specifications

Breakdown, temperature, and shock specifications are also ambiguous at times. For example, some users misinterpret the breakdown specification as equivalent to a surge. **Fig 1** gives the surge specification as between open contacts only, and the surge specification is twice the rms breakdown voltage. Surges are generally short (measured in μsec) and have considerably faster rise and decay times (dv/dt). A breakdown

TABLE 2—CHARACTERISTICS OF COMMON CONTACT MATERIALS

	Material	Characteristics
Contact material	Ag (silver)	Electrical and thermal conductivity are the highest of all metals, exhibits low contact resistance, is inexpensive and widely used. One disadvantage is that it easily develops a sulfide film in a sulfide atmosphere. Care is required at low voltage and current levels.
	AgCd (silver cadmium)	Exhibits the conductivity and low contact resistance of silver as well as excellent resistance to welding. Like silver, it easily develops a sulfide film in a sulfide atmosphere.
	AgW (silver tungsten)	Hardness and melting point are high, arc resistance is excellent, and it is highly resistant to material transfer. High contact pressure is required. Contact resistance is relatively high, and resistance to corrosion is poor. Also, there are constraints on processing and mounting to contact springs.
	AgNi (silver nickel)	Equals the electrical conductivity of silver, excellent arc resistance.
	AgPd (silver palladium)	At standard temperature, good corrosion resistance and sulfidation resistance. However, in dry circuits, organic gases adhere, and it easily develops a polymer. Gold clad is used to prevent polymer buildup; expensive.
	PGS alloy (platinum, gold, silver)	Excellent corrosion resistance, used mainly for low-current circuits. (Au:Ag:Pt=69:25:6.)
Surface finish	Rh plating (rhodium)	Combines perfect corrosion resistance and hardness. As plated contacts, used for relatively light loads. In an organic-gas atmosphere, care is required as polymers may develop. Therefore, it is used in hermetically sealed relays, such as reed relays; expensive.
	Au clad (gold clad)	With its excellent corrosion resistance, Au is pressure welded onto a base metal. Special characteristics are uniform thickness and the nonexistence of pinholes; especially effective for low-level loads under relatively adverse atmospheres; often difficult to implement clad contacts in existing relays.
	Au plating (gold plating)	Similar effect to Au cladding; depending on the plating process used, supervision is important because of the possibility of pinholes and cracks. Relatively easy to implement gold plating in existing relays.
	Au flash plating (gold thin-film plating)	Purpose is to protect the contact base metal during storage of the switch or device with built-in switch. However, a certain degree of contact stability can be obtained even when switching loads.

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voltage, in contrast, is the maximum rms voltage that a relay can withstand for some prolonged time, such as one minute.

You should use ambient temperature and temperature-rise specifications as a guide to proper relay operation. The dc coil resistance is proportional to its temperature. As the temperature of the copper coil rises, its resistance increases, causing a reduction in current (assuming the applied voltage remains the same). The pickup voltage necessary to turn the relay on increases, depending on the resistance change. Because the electromagnetic force that controls the armature movement is a function of the coil-ampere turns, the coil current determines the point at which the armature moves. To produce the equivalent current at higher coil resistance requires a higher voltage to be applied to the coil. You can calculate the pickup voltage using 0.4% rise in resistance for each degree Celsius of temperature increase.

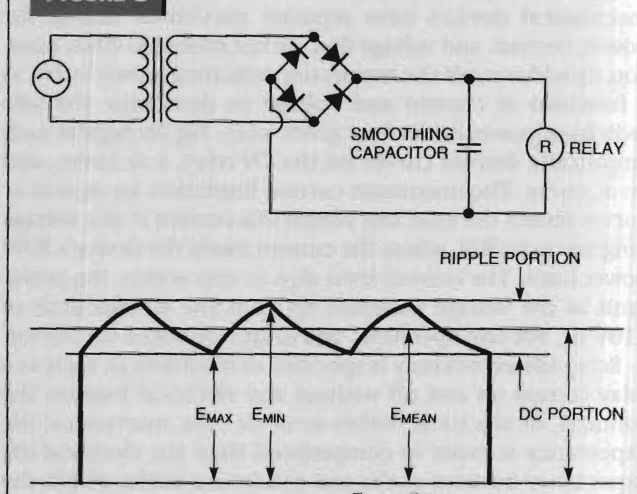
You can define shock resistance as either functional or destructive. The functional shock means that exposing the relay to a 50g shock causes the contacts to open for 10 μsec or less. In other words, the relay essentially continues to function. The destructive shock means that exposing the relay to a 100g shock could cause the relay to become inoperative due to breakage, bending, or other physical damage to its operating mechanism. At shock values between functional and destructive, the relay contacts open for more than 10 μsec but subsequently close, and the relay continues to operate.

The same terminology applies to the vibration resistance. The correct way to specify the vibration resistance is to give the vibration-frequency range and the amplitude. The specification is incomplete without the amplitude.

Relay coil needs a quality power source

When considering relay circuitry, you should pay attention to the quality of the power source that drives the relay coils. Fig 3 depicts a satisfactory common power-supply circuit, provided that the value of the smoothing capacitor is high enough, and the current drawn by the relay coil is not excessive. In general, the peak-to-peak ripple voltage should be less than 5%.

FIGURE 3



$$\text{RIPPLE PERCENTAGE} = \frac{E_{MAX} - E_{MIN}}{E_{MEAN}} \times 100\%$$

E_{MAX} = MAXIMUM VALUE OF RIPPLE PORTION
E_{MIN} = MINIMUM VALUE OF RIPPLE PORTION
E_{MEAN} = AVERAGE VALUE OF RIPPLE PORTION

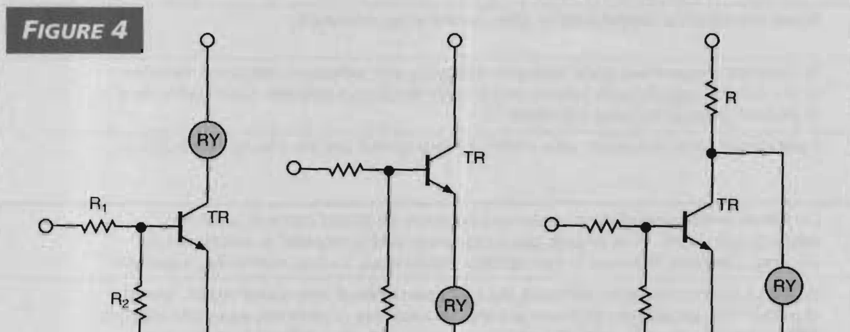
This simple full-wave rectifier is an adequate power supply for driving an EMR coil, provided the ripple voltage is less than 5%.

Fig 4 depicts several commonly used drivers for relay coils. Of the three circuits shown, you should use the one with the relay coil in the collector circuit (**Fig 4a**) to achieve good, stable operation. You can't guarantee correct relay operation for either the circuit with the relay coil in the emitter (**Fig 4b**) or the circuit with the relay coil parallel to the transistor (**Fig 4c**). For example, in the emitter-connection circuit, the transistor does not conduct completely, and the relay operation may be erratic.

For best results, signals with fast rise and fall times should turn the EMRs on and off. EMRs don't operate as expected with coil voltages that ramp up slowly. When a sharp signal pulse isn't available, you should drive the coil with a simple Schmitt-trigger circuit.

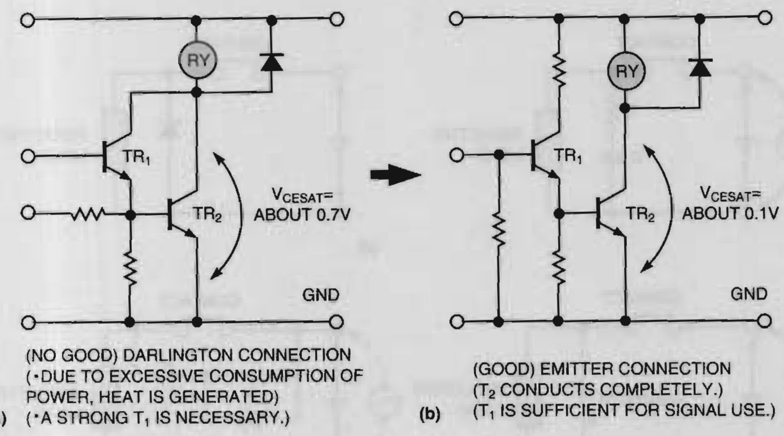
Whenever a solid-state device drives a relay coil, take care to protect the solid-state device from the relay-coil inductive kickback. The kickback is a high voltage spike that the coil generates as its magnetic field collapses after the relay turns off. Because even low currents through inductive loads can produce voltage spikes of hun-

FIGURE 4



Each of these three circuit configurations can drive a relay coil. However, the configuration in (a) is recommended.

FIGURE 5



You should avoid the Darlington connection in (a) because of a high V_{CESAT} when the driver is turned on. The emitter configuration in (b) produces the recommended low V_{CESAT}.

dreds of volts, an SSR without protection may burn on the first operation. The easiest way to suppress these spikes is to connect a diode across the coil as in **Fig 5**.

The Darlington trap

A trap that many designers fall into is placing a relay coil into the collector of a Darlington amplifier (**Fig 5a**). Relays generally require driving currents that are higher than the current that drives typical solid-state devices. Consequently, the high current amplification of the Darlington amplifier lures many users into this trap. The voltage drop across the two Darlington transistors in saturation in **Fig 5a** is approximately 0.7V. In the configuration in **Fig 5b**, the saturation voltage is approximately 0.1V. The difference in saturation voltage can be important in low-voltage circuits, such as a 3V dc circuit. In the Darlington connection in **Fig 5a**, the relay may not turn off.

The nature of a relay's load impacts its life. Relay loads fall into the following broad categories: resistive, inductive, capacitive, motor, lamp, and heater. Except for resistive loads, all loads require a good understanding of their nature and the application of suitable safeguards.

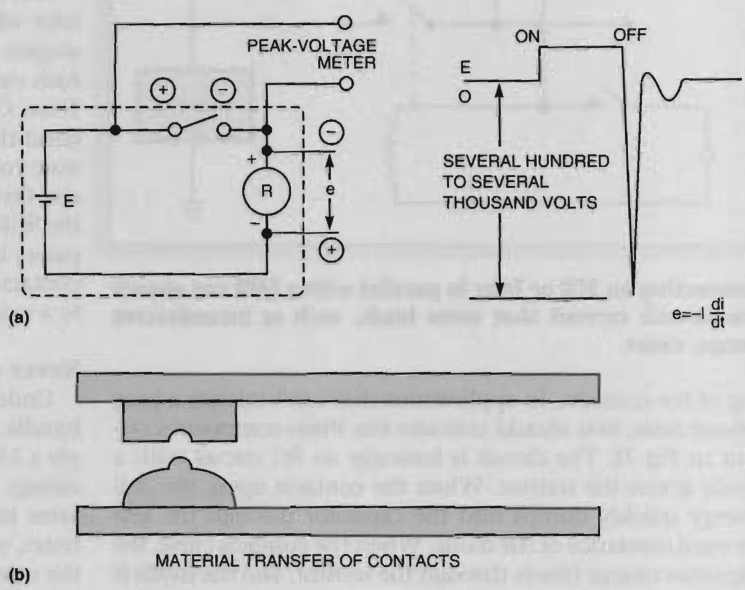
Interrupting current through any inductive load generates very high voltage spikes on the order of several hundred or thousand volts. Because these spikes can occur immediately upon contact opening, arcing can occur across this small gap and can continue as the contacts are drawn apart (**Fig 6**). As a result, contacts become pitted as melted material from one contact is transferred to the other contact. After a short time, these ball-and-socket shapes lock together, and the relay fails.

Over the years, manufacturers have developed a number of circuits to prevent the arcing problem. **Fig 7** illustrates some of the more popular options. The two RC circuits in **Figs 7a** and **b** suppress the high-voltage spike by storing the coil energy in the capacitor after the contacts open. The circuits then release the energy through the resistor after the contacts close. The diode in **Fig 7c** permits the coil energy to dissipate in the form of heat in the coil's dc resistance and the diode.

Circuit shortens release time

A problem with the circuits in Figs 7a through e is that they increase the release time of the load. If the load is a relay or a solenoid, the circuits' hold time increases because the coil current continues to flow via the arc-suppression circuit after the open-

FIGURE 6



The voltage across the relay coil can reach hundreds of volts when the relay contacts open (a). Constant opening of the relay contacts can cause arcing, in which melted metal transfers from one contact to the other, eventually leading to failure (b).

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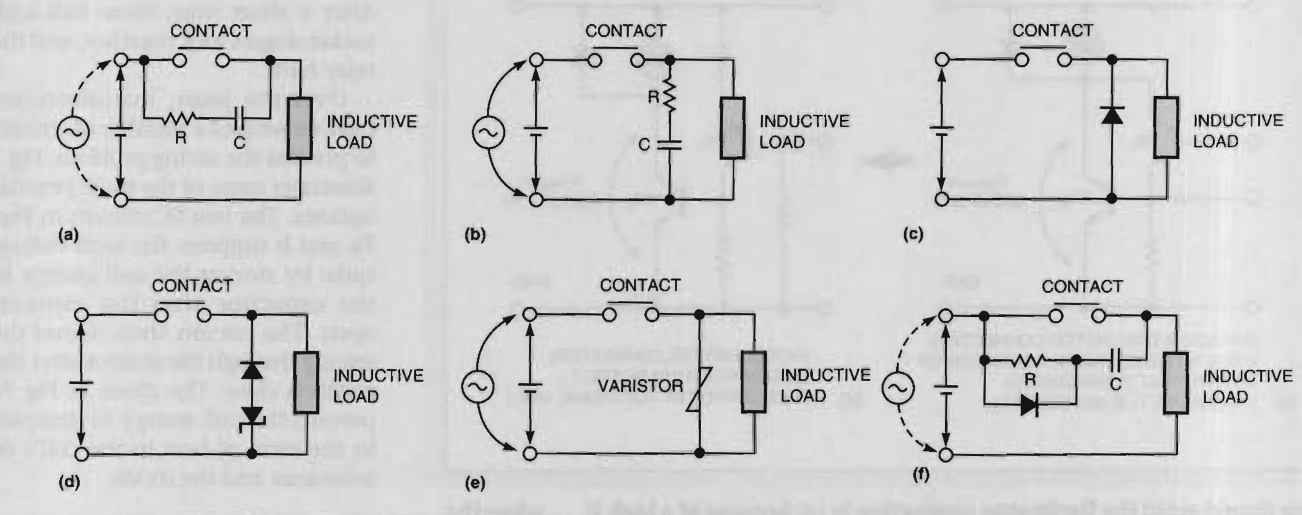
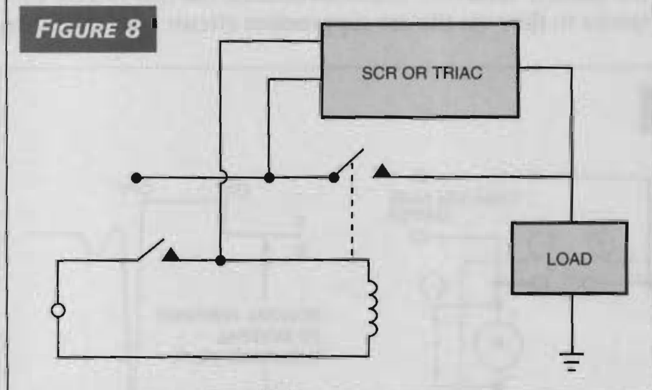
FIGURE 7



Manufacturers have developed a variety of circuits to protect the relay and adjacent circuitry against the large voltage spike when the relay contacts open.

FIGURE 8



Connecting an SCR or Triac in parallel with a EMR can absorb the in-rush current that some loads, such as incandescent lamps, cause.

ing of the contacts. In applications that can't tolerate a long release time, you should consider the three-component circuit in Fig 7f. The circuit is basically an RC circuit with a diode across the resistor. When the contacts open, the coil energy quickly dumps into the capacitor through the low forward resistance of the diode. When the contacts close, the capacitor charge bleeds through the resistor, and the diode is now off.

If you do not protect the contacts, relays driving loads that cause high-in-rush currents can also quickly cause relay failure. Typical high-in-rush current loads include capacitors, motors, and incandescent lamps. Of the three types, incandescent lamps seem to be the most troublesome because the initial lamp load is a cold resistance and about one-tenth of its final hot value. A 1A lamp draws as much as 10A at turn on. If you use a relay with contacts rated at 2A to provide a safety factor of two, these contacts are overloaded by a factor of 5 every time the relay turns on.

A brute-force way to solve the in-rush problem is to use a relay with contacts rated to pass the in-rush current. A more elegant way is to use a device that can accommodate the in-rush current but not continuous loads, such as an SCR or a Triac. Once these devices handle the in-rush current, they hand the current over to a relay that maintains the steady-state condition (**Fig 8**). A switch that energizes the relay coil also fires an SCR connected across the relay contacts. Because the SCR is much faster than the relay, the SCR turns on and passes the heavy initial-surge current. By the time the relay contacts close, shorting out the SCR, the load current drops to a value that the relay contacts can handle.

Never connect EMRs in parallel

Under no circumstances should you connect parallel to handle higher currents. For example, never attempt to supply a 3A load with two relays in parallel that have 2A contact ratings. The relay contacts never close or open at exactly the same instant, so one relay is always overloaded. As **Table 1** notes, you can connect PhotoMOS relays in parallel but not the others.

In 1994, a significant development in PhotoMOS technology produced relays that can accommodate a variety of loads without any external protective circuitry. Designated "Soft-ON/OFF PhotoMOS relays," these devices combine the best features of EMRs, SSRs, and a variety of relay-protection circuits generally known as arc suppressors or snubbers. Tran-

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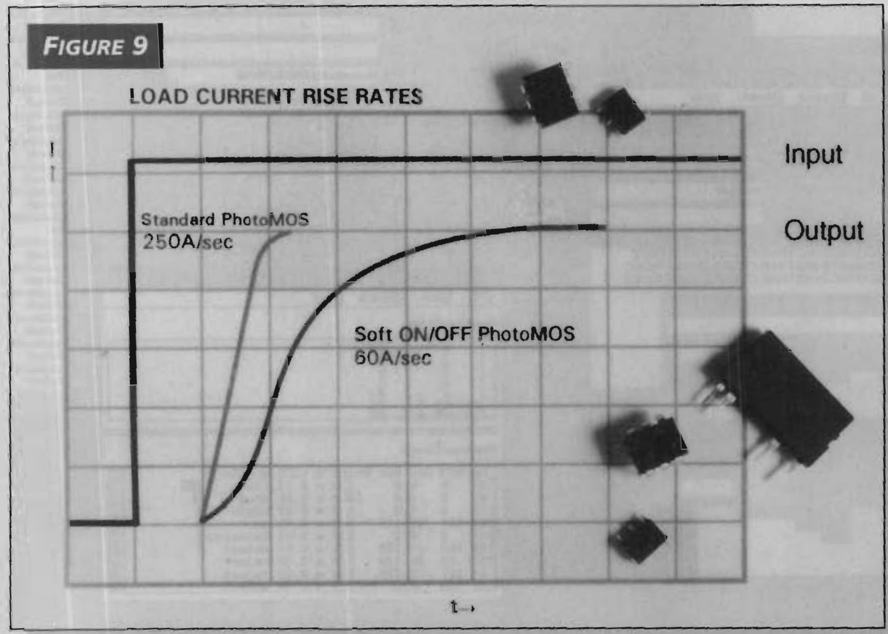
sients internally add circuitry to the standard PhotoMOS relay that extends the relay's rise and fall times, and they dissipate before damaging either the relay or the external components.

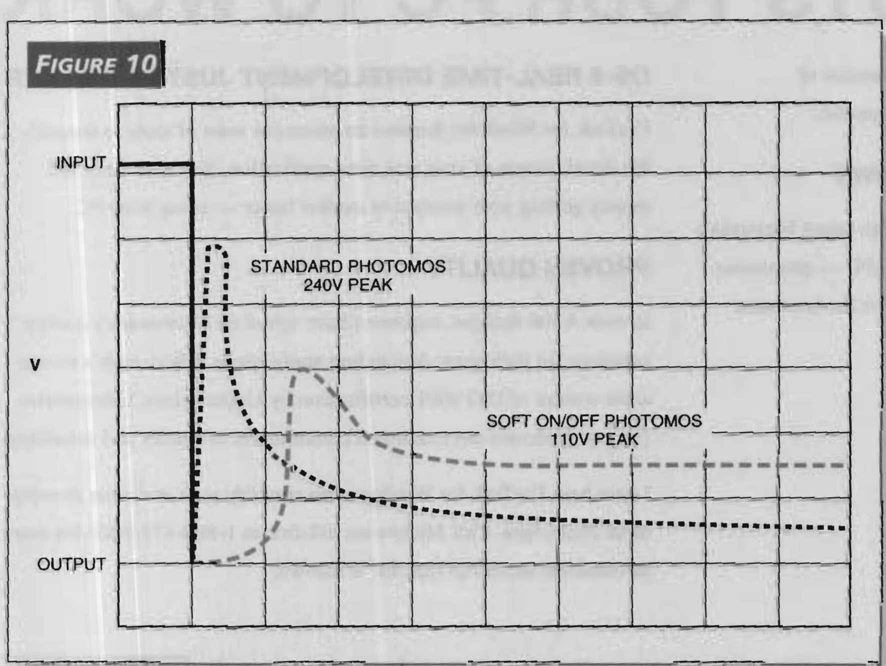
Fig 9 shows a curve of a current rise's rate into a resistive load to be approximately 250 A/sec when switched by a standard PhotoMOS relay. When the Soft-ON/OFF PhotoMOS switches current into the same load, the rate of current rise is more than four times less (60 A/sec). When the current turns off to the resistive load, the load-current fall rate is 50,000 A/sec for the standard PhotoMOS relay and only 125 A/sec for the Soft-ON/OFF PhotoMOS relay.

FIGURE 9



A Soft-ON/OFF PhotoMOS relay switches current to the load with a much slower rise time than a standard PhotoMOS relay.

FIGURE 10



When turning off an inductive load with a standard PhotoMOS relay, a large (240V) voltage spike can occur as the field in the inductor collapses. A Soft-ON/OFF PhotoMOS relay can delay and lower the peak voltage of the spike (110V).

Fig 10 shows a 240V spike that occurs when turning off an inductive load by means of a conventional PhotoMOS relay. The spike is reduced to 110V when turning off the load with a Soft-ON/OFF PhotoMOS relay. In addition to the lower spike amplitude, the Soft-ON/OFF PhotoMOS relay delays the spike and stretches it in time, which helps to reduce its impact on the switching device and surrounding components.

Work with the vendor

To ensure success of your relay circuit, you should work closely with the relay vendor. Develop strategic partnerships with your chosen relay vendor in which the companies involved cooperate in various stages of design (particularly in the early stages), manufacturing, and quality control. In these partnerships, you get an accurate, up-to-date perspective on state-of-the-art component technology, including future products. A partnership puts the relay vendor in direct contact with your company's problems and expectations.

Author's biography

Doug Lionetti is a marketing manager for the Aromat Corp in New Providence, NJ, where he has worked for 2½ years. Lionetti helped to develop the T-series signal relays and PhotoMOS SSRs. Lionetti holds a BS in electrical engineering and an MS in management science from the Stevens Institute of Technology, Hoboken, NJ. In his spare time, he enjoys golf, photography, and bicycling.

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